A literature review of sea star control methods for bottom and off bottom shellfish cultures

C. Barkhouse, M. Niles, L.-A. Davidson

Department of Fisheries and Oceans
Gulf Fisheries Centre, Oceans & Science Branch
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

2007

Canadian Industry Report of Fisheries and Aquatic Sciences 279

Fisheries and Oceans | Pêches et Océans

Canada

Canadian Industry Report of Fisheries and Aquatic Sciences 279

2007

A LITERATURE REVIEW OF SEA STAR CONTROL METHODS FOR BOTTOM AND OFF BOTTOM SHELLFISH CULTURES

By

C. Barkhouse[1], M. Niles[1], L.-A. Davidson[1]

[1]Department of Fisheries and Oceans
Gulf Fisheries Centre, Oceans & Science Branch
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

© Her Majesty the Queen in Right of Canada, 2007.
Cat. No. Fs 97-14/ 279E ISSN 1488-5409

Correct citation for this publication is:

Barkhouse, C.L., M. Niles, and L.-A. Davidson. 2007. A literature review of sea star control methods for bottom and off bottom shellfish cultures. Can. Ind. Rep. Fish. Aquat. Sci. 279: vii + 38 p.

TABLE OF CONTENTS

LIST OF FIGURES v
LIST OF TABLES v
ABSTRACT vi
RÉSUMÉ vi
1.0 INTRODUCTION 1
2.0 METHODOLOGY 2
3.0 RESULTS : LITERATURE REVIEW 2
3.1 BIOLOGY OF THE SEA STAR 2
3.2 CONTROL METHODS FOR BOTTOM CULTURES 5
3.2.1 Sea star mop 5
3.2.2 The dredge 7
3.2.3 Sea star traps 9
3.2.4 Fences 10
3.2.5 Hand picking 10
3.3 CONTROL METHODS FOR OFF BOTTOM CULTURES 11
3.3.1 Brine 11
3.3.2 Lime 12
3.3.3 Hand picking 13
3.4 POTENTIAL USES OF COLLECTED SEA STARS 13
3.4.1 Meal 13
3.4.2 Composting 14
3.4.3 Biotechnology 14
3.4.5 Arts and Crafts 15
4.0 CONCLUSION 15
5.0 ACKNOWLEDGMENTS 16
6.0 LITERATURE CITED 17
7.0 ANNEX 1 32

LIST OF FIGURES

Figure 1. Map showing scallop enhancement sites of Pecten UPM –MFU Inc. . 28
Figure 2. Species of sea stars found in the Southern Gulf of St. Lawrence: a) *Asterias vulgaris*; b) *Leptasterias polaris*; c) *Crossaster papposus*; d) *Solaster endeca*. 29
Figure 3. Sea star mop. 29
Figure 4. Scallop dredge used in Cape Tormentine, New Brunswick. 30
Figure 5. Sea star trap used on the Magdalen Islands. 30
Figure 6. Whayman-Holdsworth Sea star traps. 31
Figure 7. Fence with 45° overturned edge. 31

LIST OF TABLES

Table 1. Average and range of sea star densities found on the three Pecten sites during the 2005 video evaluations. 23
Table 2. Summary of control methods with description, where it is used, cost and corresponding papers. 24

ABSTRACT

Barkhouse, C.L., M. Niles, and L.-A. Davidson. 2007. A literature review of sea star control methods for bottom and off bottom shellfish cultures. Can. Ind. Rep. Fish. Aquat. Sci. 279: vii + 38 p.

This literature review compiles information on sea star control methods that are in use today around the world. This includes methods to control sea star predation on a variety of molluscs, including mussels, oyster and scallops, for both bottom and off bottom cultures. A summary table is presented, which includes a description of each method, where it is used, cost and corresponding literature. Methods used for bottom cultures include the sea star mop, the dredge, sea star traps, fences and hand picking, while methods used for off bottom cultures include brine, lime and hand picking. Control methods require continual efforts of removal to collect sea stars that reinvade a cleared area. Methods such as the dredge have the unique advantage of allowing for continual removal of sea stars during regular harvesting or culture activities, while other methods such as the sea star mop require separate efforts of sea star removal. The success of a control method is dependent on whether or not it is efficient, practical and cost efficient. The intention of this literature review is to present a summary of each method that will assist aquaculturists/industry to select a method that will work best for their conditions. Some methods, such as the dredge, sea star traps and hand picking, do not destroy the sea stars therefore allowing for their use after collection. Potential uses of sea stars once collected include feed for domestic animals, composting, biotechnology and arts and crafts.

RÉSUMÉ

Barkhouse, C.L., M. Niles, et L.-A. Davidson. 2007. Étude bibliographique des moyens de lutte contre l'étoile de mer dans les cultures de mollusques sur le fond et en suspension. Rapp. can. ind. sci. halieut. aquat. 279 : vii + 38 p.

Cette étude bibliographique est un recueil de l'information publiée sur les moyens de lutte contre les étoiles de mer utilisés aujourd'hui dans le monde. Elle couvre principalement les moyens pour limiter la prédation exercée par les étoiles de mer sur les pétoncles, les moules et les huîtres dans les cultures sur le fond et en suspension. Chaque moyen est décrit sommairement dans un tableau, y compris le lieu où il est utilisé, les coûts approximatifs de son utilisation, ainsi que des références pertinentes. Le Faubert, la drague, les trappes, les enclos et le ramassage manuel servent à éliminer les étoiles de mer dans les cultures sur le fond, tandis que la saumure, la chaux et le ramassage manuel sont utilisés dans les cultures en suspension. Les moyens de lutte

nécessitent souvent un effort continuel en raison de la mobilité et de la prolificité des étoiles de mer. Certains moyens tels la drague et le ramassage manuel ont l'avantage de pouvoir être incorporés dans les opérations régulières de pêche et d'aquaculture. Par contre, le Faubert et l'immersion dans une solution de chaux ou de la saumure requièrent un effort indépendant des activités régulières. Le succès d'un moyen de lutte dépend de son efficacité, de son caractère pratique et de sa rentabilité. Ce document aidera les aquaculteurs à prendre des décisions informées dans la lutte contre les étoiles de mer dans leur situation particulière. Certains moyens tels la drague, les trappes et le ramassage manuel, permettent de récolter des étoiles de mer sans les briser, ce qui présente une opportunité d'exploitation. Les étoiles de mer peuvent être utilisées dans la fabrication d'aliments pour animaux domestiques et de compost, et même en biotechnologie et en artisanat.

1.0 INTRODUCTION

Scallop enhancement is a form of aquaculture that uses the sea bottom to grow out seeded juvenile scallops to commercial size for harvesting. Pecten UPM/MFU Inc., an organization dedicated to scallop enhancement, seeded 76 million scallops over three sites in the Gulf of St. Lawrence (New Brunswick) between 1999 and 2004, at a rate of roughly 1km^2 per site per year (Fig.1). It has been suggested that a recuperation rate greater than 25% is needed for economic viability of such an enhancement venture (Hébert and Nadeau, 2002). Well below this target value, the recuperation rate for one of the Pecten sites was recently estimated at only 8% (according to video surveys). Low recuperation rates can result from many factors such as dispersal, predation, and handling mortalities. The abundance of a major predator, the sea star (*Asterias vulgaris*), at this particular site could have played a role in the survival of seeded scallops. Indeed, the greatest sea star densities were found at the Baie des Chaleurs site (80% *Asterias vulgaris*), while densities at the other two sites, Miramichi and Détroit, were much lower (Table 1). It has become necessary to find a way to reduce sea star densities to ensure the profitability of these scallop enterprises, particularly at the Baie des Chaleurs site.

The importance of reducing predators is supported by a matrix model developed by Barbeau and Caswell (1999), which was used to look at the short-term dynamics of seeded sea scallops under various scenarios. The scenarios include increasing size of seeded scallops, changing the initial density of seeded scallops, increasing the dimensions of the site and changing the season of seeding. However, the number one scenario found to increase final scallop densities was to reduce predator densities, in particular rock crabs and sea stars which have been identified as the major predators (Barbeau and Caswell, 1999).

Sea star predation is not a unique problem for scallops. It also impacts on other bivalve species such as oysters and mussels. Over the years, various methods for sea star removal/control have been developed. Early methods such as the sea star mop (Faubert), which removes sea stars from the sea bottom by entangling them in cotton bundles, are still used today. Other methods including the dredge, sea star traps, fences, brine, lime and manual removal are also practiced. Methods such as the suction dredge, the plough, heavy metals or broadcast lime application are no longer used due to their inefficiency or harmful effect on the environment. Control methods often need to be ongoing because sea stars will reinvade a cleared area. The potential of long term control methods, such as biological or genetic control, have been explored but the safety, practicality and social/political acceptability of these methods is questionable.

This document is a literature review which compiles pertinent information on sea star control methods that are used around the world. Included are methods to control sea star predation on a variety of molluscs, including scallops.

oysters, and mussels, for both bottom and off bottom cultures. A summary of each control method, its efficiency, advantages and disadvantages and cost, is presented to assist aquaculturists/industry to select a method that will work best for their conditions. Ultimately, the success of a control method is dependent on its efficiency, practicality and cost. With some of the methods discussed in this paper, sea stars are collected without being destroyed. Therefore, potential uses of sea stars are discussed in this paper as a means to recover costs associated with the control measures.

2.0 METHODOLOGY

Literature concerning methods of control for sea star predation on shellfish was gathered using the government search engines Aquatic Science and Fisheries Abstracts (ASFA) and WAVES. The internet was also used as a research tool to access non-government databases, such as ScienceDirect, and on-line publications. An efficient resource was personal communication with aquaculturists, biologists and other individuals from the industry. Over 15 communications were made in person, via telephone or e-mail. This gave us access to not readily available literature, known as "grey literature", and undocumented information. When gathering literature, priority was placed on documents concerning control methods for starfish predation that are in use today, however, past control methods and general biology of the starfish were also looked at. Information was gathered from Canada, the United States, Australia, New Zealand, France, Japan and Norway. Documents written in English and French were reviewed and summarized by separate individuals. The compiled literature was entered into a ProCite 5 database where more than 120 documents were given an identification number for future ease of locating the document when needed. Starfish control methods used on shellfish beds were reviewed, as well as control methods used for suspended cultures of molluscs. In this document, star fish size, unless indicated otherwise, refers to the diameter measurement, which is the distance between the center of disc and the end of arm, multiplied by two.

3.0 RESULTS : LITERATURE REVIEW

Table 2 was composed to summarize control methods in use today, along with a description, cost and list of literature that corresponds to each control method.

3.1 BIOLOGY OF THE SEA STAR

Four major species of sea stars can be found in the Gulf of St. Lawrence: the boreal or northern sea star (*Asterias vulgaris*), the polar sea star (*Leptasterias polaris*), the spiny sunstar (*Crossaster papposus*) and the purple

sunstar (*Solaster endeca*) (Gaymer *et al.* 2004) (Fig. 2). Although the focus in this paper will be on Asterias sp., consideration should be given to the fact that there are strong interactions between these four species. While *A. vulgaris* preys on molluscs and echinoderms including other sea stars (*A. vulgaris* and *L. polaris*), *L. polaris* preys mostly on mussels and infaunal molluscs. *C. papposus*, on the other hand, preys on a variety of echinoderms (including *L. polaris*), and *S. endeca* preys solely on sea cucumbers (Gaymer *et al.*, 2004). These predation differences stress the importance of discriminating between sea star species during abundance studies.

The geographic distribution of *A. vulgaris* extends from Labrador to North Carolina and it is considered a common sea star in Atlantic Canadian waters (Mead, 1901). This species displays a vertical distribution pattern with adults (>15 to 20 cm in diameter) found mainly at greater depths on soft bottoms while juveniles and small adults are found on hard substrata in shallow water (Himmelman and Dutil, 1991). Movement of young sea stars, as they increase in size and possibly reach sexual maturity, from the rocky subtidal zone to the low tide level is likely a result of attraction to mussel beds in the area (Himmelman and Dutil, 1991). Seasonal migration of *A. vulgaris* into deeper waters during winter is possibly a mechanism used to avoid harsh conditions in subtidal areas (Gaymer *et al.*, 2001; Gaymer *et al.*, 2002). Sea stars have a wide range of environmental tolerances. Although *A. vulgaris* can tolerate temperatures up to 25°C (juveniles 27°C) (MacKinnon *et al.*, 1993), it can not tolerate long exposure to air or salinity levels less than 16 to 18 parts per thousand (Lee, 1951).

Sea stars are dioecious, reproducing by releasing sperm and egg into the water column where fertilization occurs. The planktonic larvae then undergo a three to four week swimming stage before they settle (Needler, 1939b, O'Neil *et al.*, 1983). Sea stars have been found to reach sexual maturity when they are as little as 1 to 10g in weight (Menge, 1986). In Prince Edward Island (PEI), *A. vulgaris* spawns in May or early June (MacKinnon *et al.*, 1993; Needler, 1939b), however, this is not always the case as they have been found to spawn at various times. For example, a study done in Brudnell River, PEI, found the majority of sea stars did not spawn until mid July (MacKinnon *et al.*, 1993). In Newfoundland and the Magdalen Islands, settling of sea star larvae has been observed from mid summer to early autumn, approximately a month after the peak mussel set (Pryor *et al.*, 1999; Bourque and Myrand, 2003). In general, reproduction and growth rates of *A. vulgaris* will vary depending on food abundance and temperature (McKinnon et al, 1993; Menge, 1986). Sea stars can grow 50 to 54 mm (arm length) in four months from time of settling (Mead, 1901).

The blue mussel, *Mytilus edulis*, is the preferred prey of *A.vulgaris* and has been found to make up 80-100% of *A. vulgaris*'s diet (Gaymer *et al.*, 2001.). With greater depth and a decrease in mussels, *A. vulgaris* has been found to switch prey preferences to species such as the brittle star (*Ophiopholis aculeate*)

and the arctic rock borer (*Hiatella arctica*)(Gaymer *et al.*, 2001.). Sea stars also prey on oysters, scallops, snails, barnacles, small crustaceans, worms, and dead fish among other intertidal and subtidal organisms. Sea stars are dominant predators in the northern Gulf region, and do not have any real predators except for other larger sea stars (Gaymer *et al.*, 2004; M. Hanson, pers. comm., 2006). Events of cannibalism for *A. vulgaris* have been observed (Witman *et al.*, 2003; Gaymer *et al.*, 2001). Sea stars (~ 30 mm diameter) have been found in the digestive system of lobsters (*Homarus americanus*), however, they were only present when shed rock crab carapaces were also present (M. Hanson, pers. comm., 2006). It was thought that young sea stars attach to rock crab carapaces, which are then eaten by lobsters. Stomach analysis also showed sea stars to be present in small amounts in cunners (*Tautogolabrus adspersus*), American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*) and winter flounder (*Pseudopleuronectes americanus*) (Comeau *et al.*, 2004).

Sea stars use the suction of their tube feet to open bivalves in order to allow their inverted stomach to digest their prey within the shell. Sea stars can eat up to 1% of their body weight per day (MacKinnon *et al.*, 1993) and they have been found to spend less than 10% of their time searching for prey (Nadeau et Cliche, 1998). The number of bivalves sea stars eat per day has been said to be anywhere from less than 1 scallop per day (Nadeau and Cliche, 1998) and up to three adult bivalves or more than 15 oyster spat per day (Flimlin and Beal, 1993). Variables that affect sea star predation include water temperature and prey size (Barbeau and Scheibling., 1994). They found that the consumption rate of small scallops (5-8.5 mm) was greater at 15°C than at 4°C or 8°C. They also found that sea stars 30 to 150 mm in diameter consumed more small (5-8.5mm) scallops than medium (10-15mm) or large (20-25mm) scallops and that large sea stars (120-150mm diameter) had a higher consumption rate than medium (60-75mm diameter) sea stars. However, other studies have not seen a clear prey size preference in sea stars when given choice and non choice treatments (Nadeau and Cliche, 1998).

Studies have found that sea star predation rates increase with increasing prey densities (Barbeau *et al.*, 1998; Barbeau *et al.*, 1994; Gaymer *et al.*, 2001), therefore displaying a functional response as opposed to an aggregative response. A study by Inglis and Gust (2003) looked at sea star densities beneath active marine shellfish farms and found sea star densities to be 14 to 39 times higher compared to non farm areas in the same bays. It is thought that the abundant prey available favours growth, increased gonad production, greater reproductive output, and prolonged proximity to conspecifics. Theoretically, according to Barbeau and Caswell's (1999) matrix model, high densities (>3/m^2) of sea stars resulted in poor seeded scallop survival but low and intermediate (1/m^2) densities could be acceptable.

3.2 CONTROL METHODS FOR BOTTOM CULTURES

3.2.1 Sea star mop

The sea star mop is a physical control method used by aquaculturists to protect shellfish beds from sea star predation. There is some variation in sea star mop models; however, in general a sea star mop is made up of a number of cotton bundles (ranging from 4 to 19) attached to a frame (such as a 2.5 to 3 meter iron bar used by scallop and oyster dredges), which is towed behind a boat (Figure 3) (US Fish and Wildlife service, 1946). Bundles usually measure about 1 meter in length. As the sea star mop passes over the sea bottom, sea stars become entangled in the threads of the cotton bundles. Typically, the sea star mop is dragged for 10 to 15 minutes before it is brought up on deck (McEnnuly *et al.*, 2001), however, the time of treatments may vary such as in Connecticut where 3 minute trials are done (D. Hopp, pers. comm., 2006). Once on deck, the sea stars are either removed by hand, to be disposed of later, or killed by submerging the mop into a basin containing hot water. The temperature of the hot water and the amount of time the mop is submerged vary. However, Presse *et al.* (2005) found the optimal submersion time to be 30 to 60 seconds in water between 40°C and 50°C. Other suggested alternatives include submersion in brine, lime or freshwater. With two mops, such as in side drags, time and expenses can be saved by towing one mop while sea stars are being removed from the second (Needler, 1939a).

There has been some concern over the impact of mopping on local flora and fauna (McEnnuly *et al.*, 2001), however, in general the mop is considered to cause little disturbance to the sea bottom (Press *et al.*, 2003a.). From as early as the 1930's, the sea star mop has been used by aquaculturists on the Atlantic coast of Canada and the US to protect their oyster stocks (Needler, 1939a; McEnnuly *et al.*, 2001; Smith, 1940). Needler (1939a) considered the mop to be the most effective method at removing sea stars in the 1930's. In the 1990's, a mop known as the "Faubert" was used in France to remove *Asterias rubens* from oyster beds in the Bay of Quiberon (southern Brittany) (Barthelemy *et al.*, 1991). Traditionally, the Faubert was used once or twice per week by the farmers in Ireland (Heffernan, 1999). The mop has also been used in Japan over reseeded scallop cultures as part of the "Hotate"-aid-conglomerate (HOTAC) method (McEnnuly *et al.*, 2001), which was developed to increase the success of bottom culture Japanese scallops (Ito, 1991). The HOTAC scallop culture technique involves the use of scallop dredges and traps to remove sea stars before reseeding and mops and traps to remove sea stars after reseeding (McEnnuly *et al.*, 2001). There are also plans to use the sea star mop in Maine to manage cultivated mussel beds (Hendrix, 2006). There has also been mention of an alternate form of mopping used in Connecticut where sea stars are picked up by their spines with the use of a rotor cable (Anon. 2006).

The effectiveness of the mop varies depending on bottom type as well as working conditions (Needler, 1939a.). Smith (1940) looked at the efficiency of

the mop using the mark and re-capture method and reported that 86% of the sea stars were recaptured in 28 hours. In the summer of 2001, trials using the faubert to remove sea stars from the Havre-Aubert basin (Magdalen Islands, Quebec) reported, through diver observation, that approximately 90% of the sea stars in the path of the Faubert were being collected (Bourque and Myrand, 2003). In September of 2001, the scallop grower company Pecten UPM/MFU looked at the efficiency of the Faubert in the Baie des Chaleurs using video footage before and after mop treatments. Only three passes were done along the same transect, nevertheless, sea star densities were reduced from 0.57 to 0.47 sea stars/m^2 (17% reduction) (Pecten, 2002).

The mop is best used on areas of a medium scale with high densities of sea stars (Goggin, 1998). With sea star densities of approximately 1 sea star/m^2 in the Baie des Chaleurs, the company Pecten collected an estimate of 15,000 sea stars per 20 minute mop treatment from their seeding site (Pecten UPM/MFU, 2002). However, lower collection numbers of 50 sea stars per 5 minute treatment were reported from using the Faubert in the Havre-Aubert basin (Magdalen Islands, Quebec) (Bourque and Myrand, 2003). This difference in numbers of sea stars collected per treatment also reflects a difference in mop size. For example, the mop used in the Baie des Chaleurs had 19 cotton bundles (Pecten , 2002), whereas the Faubert used in the Havre-Aubert basin had only 4 cotton bundles (Bourque and Myrand, 2003).

In the protected bays of Connecticut, sea stars are commonly killed by submerging the mop in hot water (Presse *et al.*, 2005). The sea stars become softened by the hot water, which allows them to passively fall off the mop when it is placed overboard for the next treatment (Lee, 1948; Presse *et al.*, 2003.). However, problems arise when this method is used in rough sea conditions, such as off the coast of the Magdalen Islands, Quebec. Rough seas can cause the hot water to spill out of the basin posing serious threats to crew on board (Presse *et al.*, 2003.). Using alternative options for rough sea conditions, such as salt brine, would not solve the problem of spillage or the need to replace the solution time and time again (M. Nadeau, pers. comm., 2006). Furthermore, brine would not soften the sea stars, therefore making them more difficult to remove from the mop in between treatments (Presse *et al.*, 2003.). Removal of sea stars from the mop by hand is time-consuming and is considered to be expensive (Needler, 1939a).

Operational cost of the mop varies but it involves the cost of running the boat (including fuel), labour wages for at least two individuals, and wear on the mop (Needler, 1939a.). In trials performed in the Magdalen Islands, longevity of the cotton bundles was low and they needed to be replaced periodically (approximately every 3 days) (Presse *et al.*, 2005.). The initial cost to equip a fishing boat with a boiler system was estimated at about $10,000 per system. They stated an estimated cost of $43,000 ($0.06/sea star) to cover a 4 km^2 area with the Faubert over 16 days (roughly $2700 per day). This includes the cost of

the initial set up of two boiling systems and two Faubert as well as the replacement of cotton bundles and cost required to run the boat. Costs can be reduced if a fishing boat already has a frame for the mop (from their dredge) or if alternate methods are used to remove the sea stars from the mop that don't require the boiling system. In the long run, the longevity of the frame is also a consideration.

In Connecticut, the cost per day per boat, which includes 7 hours of mopping and 3 hours of sailing, was estimated at $1400CAD (D. Hopp, pers. comm., 2006). This is based on three minute treatments with the use of an 8 foot tow bar with 12 cotton bundles and a 65 foot boat. Sea stars are collected with the mop 12 months a year on a daily basis by two boats that cover a 20,000 acre oyster lease. If sea stars densities are not too high, approximately 100 acres can be covered in one day. Sea stars are removed from the mops by soaking them in heated salt water or removing by hand if there are fewer than 30 sea stars entangled per mop.

3.2.2 The dredge

The primary function of the dredge is to collect scallops, oysters or mussels from the sea bottom, however, the dredge also catches sea stars (Figure 4). Therefore, the dredge can be used to control sea stars during harvesting of target species. In Japan, the dredge is used as part of the "Hotate"-aid-conglomerate (HOTAC) method of scallop enhancement, where the scallop dredge is used to remove sea stars prior to scallop reseeding (Goggin, 1998). The "roller dredge", a modified dredge that uses a front roller to suspend the sea stars before gathering them into a rear bag, has been used in the Dutch subtidal oyster beds to collect *Asterias rubens* (McEnnuly *et al.*, 2001). In France, sea stars were selectively harvested from oyster beds using a specialized dredge that had been developed with the help of professionals (Barthelemy *et al.*, 1991). Although details of this dredge were not available, its efficiency seemed promising according to diver observations (Barthelemy *et al.*, 1991).

In the Tokoro and Shari area of Japan, the dredge is used before reseeding to clean up a fishing ground and then again four years later when the scallops are to be harvested (M. Kurata, pers. comm., 2006). Densities of sea stars in the Shari area are 0.19/m^2 (*Asterias amurensis*) and 0.10/m^2 (*Distolasterias nippon*), while in the Tokoro area they range from 0.06/m^2 to 0.156/m^2 for both species. Only about 5 persons are involved in sea star collection and approximately 150 tonnes, during a 120 day operation, are collected each year.

According to Goggin (1998), the dredge is best used for medium to small scale areas with high densities of sea stars. In 1998, five dredge equipped boats were used over a four day period to remove sea stars from a 2.3 km^2 area off the coast of the Magdalen Islands, Quebec (Nadeau and Cliche, 2000). The density

of total sea stars (all species combined) in this area was reduced by 50% from 0.06/m^2 to 0.03/m^2 (Hébert *et al.*, 2006). However, this reduction mostly comprised *S. endeca,* which is not a shellfish predator. In fact, video surveys conducted prior to dredging revealed that sea star composition was dominated by *S. endeca* (47%). The other species, *A. vulgaris*, *L. polaris* and *C. papposus* accounted for 5%, 27% and 21% of the sea star composition, respectively. The cost of this operation was estimated at $45,000. Ninety percent was associated with the cost of running the boats and the remaining 10% was associated with weighing and composting fees. The efficiency of the dredge in collecting sea stars is considered to be quite low (<10%). For this effort to have recovered its costs, harvesters needed to recuperate an additional 9.3% of the 5.4 million scallops seeded, which seems unrealistic (Nadeau and Tita, 2005). Also to consider is that the dredge captures larger sea stars, such as *S. endeca* and *C. papposus*, more easily than smaller sea stars, such as *A. vulgaris* and *L. polaris* (Press *et al.*, 2005). Nevertheless, the dredge presents the advantage of being able to concomitantly remove sea stars during regular harvesting of target species, such as scallops, oysters, and mussels, rather than requiring isolated efforts, by mopping for example.

During regular dredging for scallops, oysters or mussels, the sea stars caught with the dredge are often thrown back over board because of the time and effort that is required to collect them. Furthermore, there is the question of what to do with the sea stars once collected. However, incentive programs that pay per pound of sea star have encouraged aquaculturists to bring the sea stars back to port. A program such as this was put into place on the Magdalen Islands, Quebec for one year commencing in July of 2001. A total of about 60 000 kg or 900,000 individuals were collected, which reduced the population of sea stars by 14% (from 0.35/m^2 to 0.30/m^2) over a total area of 17.9 km^2 (Presse *et al.*, 2003). The sea stars were later used for compost (M. Nadeau, pers. comm., 2006). The cost of this operation was just over $47,000 or $0.052 per sea star, which includes paying for the collection of sea stars ($0.22 to $0.55 per kg to fishermen), the compost program ($0.036/kg) and program employees wages (Presse *et al.*, 2003; D. Hébert, pers. comm., 2006). Similarly, in New Zealand, the primary control method for *Coscinasterias sp.* is a competition that rewards scallop fishermen for collecting the most sea stars while dredging for scallops (R. Mincher, pers. comm., 2006). The individual who collects the most sea stars each week wins $20 CAD and three top prizes ($1,000 total for all three) are given out annually to whoever collects the most sea stars over the season. Sea stars brought into port are weighed by the processors and later disposed of in their waste bins. During the 2005/2006 season, the reported landings of sea stars from Golden Bay, Tasman Bay, and Marlborough Sounds in New Zealand were 10.8 tons. This works out to be an average of 9.66 kg per day over 1,121 day trips. Collecting sea stars with the dredge allows for the opportunity to use the sea stars for other purposes, such as for fertilizer, in contrast to sea stars collected with the mop, which are killed and returned to the water.

3.2.3 Sea star traps

The abundance of sea stars is a major concern for scallop enhancement in Mutsu Bay, Japan. Dredging alone does not sufficiently reduce this abundance, therefore traps are deployed in a longline fashion. Two types of traps are used; one is a modified crab trap with a mesh size of approximately 15mm, and the other is a domed shaped trap with opening on the top (Cliche, pers. comm. 2006). In the Magdalen Islands, Québec, similar sea star traps were baited with crushed mussels and deployed for 3 days (Figure 5) (Presse *et al.*, 2003) Each trap caught an average of 30 and a maximum of 80 sea stars (Bourque and Myrand, 2003). Although the traps were effective in catching sea stars, much time and effort are needed to deploy and retrieve the traps (F. Bourque, pers. comm., 2006). Travel to and from the cages remains the main drawback of using the control method. In 2000, on Prince Edward Island, sea star traps were used for two months to collect a total of 8058 sea stars by raising cages 668 times (Presse *et al.*, 2003.). Using cages for large scale removal of sea stars does not seem practical due to the high costs associated with the labour required (Presse *et al.* 2003, F. Bourque, pers. comm., 2006).

There has been some experimentation to increase catch rates of a variety of sea star trap models. In 1993, the effectiveness of Tasmanian designed sea star traps at catching introduced sea stars was looked at by the National Sea Star Task Force (Anon., 1994). The traps were baited with salmon heads, which attracted sea stars within an area of approximately 10 square meters. They found it's effectiveness to be two to three times greater compared to the Japanese designed sea star traps, however, sea star species other than the targeted introduced northern Pacific sea star were also caught.

Whayman-Holdsworth sea star traps (Figure 6) were used in 1999 by the Tasmanian Marine Farm Marine Pest Monitoring Project in efforts to trap the introduced northern Pacific sea star (Martin and Proctor, 2000). The traps were baited with salmon pellets and later baited with fish and shellfish. They found the method to be ineffective in areas where sea stars were found in low densities and in areas where other food sources were abundantly present. Also, the suggested weekly deployment of traps was not easily maintained (Martin and Proctor, 2000). Other studies using Whayman-Holdsworth sea star traps looked at their potential efficiency of preventing sea stars from entering a cleared area by placing traps 2.5 m apart around a perimeter (Goggin, 1998). The traps were found to be unsuccessful at stopping sea stars from migrating into the cleared area. Sea stars can travel up to 20 feet (6.2m) per day and slowly invade a cleared area (Needler, 1939b.).

In summary, sea star traps may be efficient to use in small enclosed areas (F. Bourque, pers. comm., 2006) where there is a high abundance of sea stars and low alternate food sources available. Catch rates of sea star traps are highly

variable and the use of 26mm mesh has shown to be more efficient at catching sea stars compared to a larger 65mm mesh size (Goggin, 1998). To capture sea stars they must be large enough to be retained within the trap (McEnnuly *et al.*, 2001). Using sea star traps needs to be fine tuned for each season and in terms of their strategic deployment according to factors such as sea star density, currents, etc... (F. Bourque, pers. comm., 2006). These traps do not protect off-bottom cultures since sea star larvae can settle on mussel lines, scallop collectors, pearl nets and oyster trays (Martin and Proctor, 2000).

The cost of using sea star traps includes the cost of each cage (approximately $65.00 each) (Y. Chiasson, pers. comm., 2006), fuel to travel to and from the traps, wages for labour and bait. However, the cost of travel to and from open ocean sites could be negligible if growers are going to the site daily for other activities and traps are being incorporated into their daily activities. An additional cost to be taken into consideration is the cost of replacement cages from broken or lost cages (F. Bourque, pers. comm., 2006).

3.2.4 Fences

Fences are an exclusion method, which are used to protect scallops from predation. Most research to date concerning the use of fences has focused on the exclusion of crabs. A study done in Norway found that fences increased the survival rate of 50mm size scallops from 5% (without fences) to 89% (Strand *et al.*, 2003). However, the sea star, *A. rubens*, was thought to be responsible for the mortality of scallops in the fenced area (Strand *et al.*, 2003). One study looked at the exclusion of both crabs and sea stars using a 1m high fence with a 45° overturned edge of 15cm and embedded 20cm into the substrate (Figure 7) (Boudreau *et al.*, 2005). Predators were removed bi-weekly by diving and were thus reduced by a factor of 5 to 7 within the enclosed area.

The Great Barrier Reef Marine Park Authority (Anon., 1995) experimented with a steel wire mesh fence (one meter high) with a 60 cm overhang at the top to control crown-of-thorns sea stars. They found the fence to be an effective barrier for this species of sea stars, however, there were some drawbacks with the method concerning cost and up-keep of the fence. The cost of the fence is high with materials running at approximately $8.45 CAD/meter. The fence is difficult to set up in rugged areas and there will be additional maintenance costs associated with damage to the fence due to rough sea conditions. Furthermore, fences did not stop juvenile sea stars from migrating or sea star larvae from settling into the protected area. Although numerous studies have shown fences to be effective in controlling crabs, the effectiveness of fences against sea stars has not fully been explored.

3.2.5 Hand picking

In shallow waters, sea stars may also be collected from the sea bottom by hand, either with or without the help of diving equipment. In Miscou, NB, sea

stars are collected from the Chiasson Aquaculture Ltée. oyster grounds during harvesting (Y. Chiasson, pers. comm., 2006). Two employees spend approximately 100 days between May and November harvesting oysters, during which approximately 10% of their time is dedicated to removing sea stars. Numbers in the order of 200 sea stars are collected on a daily basis (Y. Chiasson, pers. comm., 2006). Sea stars are then disposed of by placing them with other organic waste to be composted for a disposal fee of $20.00/lb.

In May 2000, a sea star "round-up" was organized in the Derwent River (Tasmania, Australia), in which more than 20,000 northern Pacific sea stars (*Asterias amurensis*) were collected by 200 volunteers over a two day period (Anon., 2000). Sea stars were collected for the most part by divers; however, there were also four snorkellers who collected approximately 1,000 sea stars. As a way of measuring the success of the "round-up", the sites were monitored before, after and 2 months after the sea star "round-up". Results indicated that the "round-up" was successful in decreasing sea star populations by approximately 6.5% to 29.9% from the three sites. However, it was suggested that this amount is not likely to make a big impact on total sea star densities. Furthermore, collection by hand is extremely labour intensive (Anon., 1999).

3.3 CONTROL METHODS FOR OFF BOTTOM CULTURES

Brine and lime treatments are typically used to control sea stars on spat collectors. However, these types of treatments are not used on scallop growing structures since scallops are vulnerable to exposures to these solutions. Hand picking, however, can be applied to all molluscs growing off bottom structures.

3.3.1 Brine

Brine, a saturated salt solution, has been used to remove settled sea stars from mussel collectors. Osmotic stress on the sea stars causes them to detach from the collectors, while the mussels remain unharmed. Bourque and Myrand (In Press) treated mussel collectors by submersing them in a brine solution for 30 seconds in mid-August before sea stars reached 15 mm diameter, approximately two weeks after the first observations of sea stars with the naked-eye. Two months later they looked at mussel yields and found that treated collectors had 2900 mussels per meter while untreated collectors had only 1300 mussels per meter (Bourque and *Myrand*, 2002). Treatment therefore doubled mussel yield. The effectiveness of brine is dependent on the strength of the solution, as well as submersion time. Trials in the Magdalen Islands found that increasing submersion time in oversaturated brine (300g/L) from 5 to 10 seconds to 30 seconds was more effective, resulting in the complete elimination of sea stars (Bourque and Myrand, in press). When conducting treatments in the fall (September), it was necessary to increase submersion time to 40 seconds. The amount of time needed for treatment was estimated at approximately 5 days to treat 60 lines. In commercial trials at two mussel farms (farms had 44 and 60

longlines), brine treatments could increase the seed harvest by 12 to 16 t at a cost of approximately $4000 for each farm (Bourque and Myrand, in press). Depending on the farm scenario and mussel price, this could translate into profits of between $10 000 and $33 000 for market-size mussels. While refraining to commit to a specific sea star density at which treatment is viable, the authors did not suspect problems when densities were below a dozen sea stars per meter.

Mussel growers in Prince Edward Island (PEI) normally start treatment at densities anywhere between 7 and 12 sea stars per collector, some even systematically treat all collectors (B. Fortune, pers. comm., 2006; Rogers, pers. comm., 2006; Somers, pers. comm., 2006). While they prefer hydrated lime as a treatment to control sea stars, they have been using brine or a mixture of brine and hydrated lime over the past three years to control green algae (*Entermorpha* sp.) and sea stars when both are present. Lime treatment is discussed in the next section.

MacKinnon *et al.* (1993) found brine unsuccessful in removing sea stars from mussel collectors (). However, this may have been a question of whether or not the solution was strong enough to cause osmotic stress to the sea stars. Mussel spat collectors were placed in a 17 g/liter solution for 60 seconds. Shearer and MacKenzie (1961) looked at the effects of salt solutions of different strengths on sea stars and found that sea stars did not die in less than 50 per cent saturated solution when submerged for 15 minutes.

3.3.2 Lime

Although broadcast application of lime has not been practiced in recent years due to its potential harmful effects on other non-target organisms, lime is being used to remove sea stars from mussel spat collectors. In August of 1992, mussel collectors from Stanley River, PEI were treated with both quicklime and hydrated lime solutions (MacKinnon *et al.*, 1993). Treatments consisted of 30 second submersion in Quicklime and 5, 10 and 20 second submersions in hydrated lime. Both were effective in removing sea stars, however, it was recommended that hydrated lime be used rather than quicklime due to safety reasons. After a single treatment with 40g/l concentration of hydrated lime, observations two days and ten days later revealed that 95% and 98% of sea stars had been removed respectively. It was recommended that collectors be treated within a short time (2 weeks) of noticing the settled sea stars or before they reach 15 mm (MacKinnon *et al.*, 1993). PEI mussel growers reported that they treat spat collectors with oversaturated hydrated lime during the last week of July or the first week of August. If needed, they treat a second time during the third week of August. Using one boat, a crew of two can treat 20 lines per day. Operational costs were estimated at between $20 and $100 per line of collectors. Depending on the size of the farm and the extent of infestation by sea stars, annual costs vary from $600 to $20 000 (Fortune, pers. comm.; Rogers, pers. comm.; Somers, pers. comm.).

3.3.3 Hand picking

Sea stars can be hand picked off of suspended shellfish gear, however, a considerable amount of time is needed and operations may be slowed down because of this. For example, Chiasson Aquaculture Ltée. removes sea stars by hand at the same time as seed is being sorted before being socked. This is done between the months of September and November and the amount of time dedicated to removing sea stars is approximately one hour out of an 8 hour work day (Y. Chiasson, pers. comm., 2006). To further help alleviate the problem of sea star predation, mussel lines are kept off the bottom to prevent sea stars from climbing up the lines. At the grow-out site, one mussel line can yield up to five fish tubs of large sea stars (Rogers, pers. comm.). One advantage to hand picking sea stars is that the collected sea stars can be used afterwards, whereas the sea stars treated with brine or lime can not be.

In Japan, the sea star *Asterias amurensis* are removed from scallop collector bags by sorting the scallop spat while they are still very small (Ventilla, 1982). *Asterias amurensis* larvae grow twice as fast as scallop spat and therefore need to be removed as early as possible (Ventilla, 1982). *Asterias amurensis*, if left within the scallop collector bags and grow-out nets, are capable of causing mass mortalities of up to 90%. The scallop company Pétoncles 2000 (Québec) and Pecten (New Brunswick) also remove sea stars by hand during the sorting process preceeding transfer of scallop spat to the grow-out cages.

3.4 POTENTIAL USES OF COLLECTED SEA STARS

Presently, in Canada, sea stars are not fished commercially. In 1946, the Bingham Oceanographic Laboratory published a report on the possible uses of sea star (*Asterias forbesi desor*)(Heuser and McGinnis, 1946). His conclusions concerning marketability of sea stars are still applicable today. As stated by Nelson in 1946, the commercial use of sea stars depends on the technical developments which will make it sufficiently profitable to harvest them. Furthermore, commercialization of sea stars also depends on a secure market, a receiving station and a stable adequate price (Heuser and McGinnis, 1946).

3.4.1 Meal

Lee (1951) who studied the chemical composition of sea star (*Asterias forbesi*) concluded that fresh sea stars will yield one ton of meal per four tons of raw material. Sea star meal contains about one half the proteins of that of fishmeal but compares favorably to meal prepared from crab or lobster scrap and shrimp bran. Sea star meal is high in calcium carbonate, while potassium and phosphorus are disproportionately low. In fact, sea star meal is composed of 34% protein and 42% calcium carbonate (Morse *et al.*, 1946) and less than 1% phosphorus (Houser and McGinnis, 1946; Whitson and Titus, 1946). The protein portion contains some of the essential amino acids.

During World War II, an interest in marine protein for use in poultry and stock feeds was investigated (Morse *et al.*, 1946). Experiments provided evidence that sea star meal could be used satisfactorily as one of the protein concentrates in chick rations. However, the high calcium content of sea star meal limits the amounts that can be fed to chicks. Six per cent is probably the maximum amount that can be used effectively. They found that if an allowance is made for the high calcium and lack of phosphorus, as much as 8% of sea star meal can be used in chick feeds. Ringrose (1946) suggested that monocalcium phosphate or other high phosphorus carriers would be needed to bring the calcium:phophorus ratio into balance.

In a more recent study, Xu *et al.*, (1995) found that the protein content of sea star (*Asterias rollestoni)* gonads is 15.92% and includes eight essential amino acids. The gonads had a fat content of 11.13 % and contained eight essential microelements including zinc, and vitamins A, B_1, B_2, B_6 and B_{12}. The sea stars were prepared into health diets or feeds for fish and shrimp which gave better results than fish meal.

Sloan (1984) has reported that sea stars are processed and exported to West Germany as an additive to fin-fish meal for poultry and feed stocks. However, the three feed companies contacted (Land O'Lakes Purina Feed, US; Martindale Feed Mill, US; Corey's Feed Mill Ltd., CAN) were not using or even aware of sea star meal.

3.4.2 Composting

In Japan, scallop fishers retain the sea stars during their harvesting operations on enhancement beds using dredges (Mamoru Kurata , pers. comm., 2006). However, fishers must pay composting companies for the disposal of these sea stars. One Japanese company (Hokkaido Environment Bio-Sector Ltd., 2004) has developed a "Power LiveLand bacteria", which combined with sea stars, water, and sawdust, makes a high quality odorless compost product. In New Brunswick, the Westmorland –Albert Solid Waste Corporation and the Fundy Region Solid Waste Commission have a composting program but do not presently compost sea stars. Nevertheless, managers from both treatment plants expressed interest in incorporating sea stars into their program. Important items to consider are the Carbon/Nitrogen balance and heavy metals concentration. Heavy metals criteria are listed in the Guideline for Compost Quality (Canadian Council of Ministers of the Environment, 2005).

3.4.3 Biotechnology

Sea stars have the remarkable ability for regeneration. When a sea star loses a ray, it can grow a whole new one, given time. In the near future, this regeneration process could be studied for medical purposes (M. Nadeau, pers.

comm., 2006). The brittlestar, *Amphiura filiformis*, a close relative of the sea star, can regenerate lost rays in a matter of weeks. Scientists at the Royal Swedish Academy of Sciences Kristineberg Marine Research Station are using the brittlestar as a new model for studying stem cells, allowing them to conduct experiments that avoid the ethical issues associated with human and vertebrate research (Dupont *et al.* 2006). The researchers are particularly interested in studying the recovery of the nervous system which could have applications for understanding and treating neurodegenerative diseases.

Another medical application relates to the field of cancer treatments where Cytotoxic natural products are used. In fact, extracts from the mud star (*Ctenodiscus crispatus*) have shown considerable cytotoxic activity (Gudbjarnason, 1999).

3.4.5 Arts and Crafts

Sea star can be dried and use decoratively or in the creation of art and crafts. Companies such as Shell Horizons Inc. (1998) are in the business of selling dried sea star for this purpose. Art and crafts stores (ex: Créations Marie-Gaudet, Gaspé, Qc) sell dried sea stars ranging in price from $3 to $45CAD each depending on size.

4.0 CONCLUSION

With this literature review we were able to compile information on sea star control methods used around the world. For the Gulf of St Lawrence, two major species are of concern for shellfish culture, *Asterias vulgaris* and *Leptasterias polaris*. Predation can compromise the success of enhancement efforts and aquaculture endeavors, therefore the removal of sea stars should be considered in shellfish aquaculture operations. Yet, the critical sea star density at which the cost of removal is justified could not be found in the literature. Theoretically, densities greater than $1/m^2$ have an impact on seeded scallop survival. Sea star densities as high as $2.5/m^2$ have been observed on the scallop enhancement Pecten sites in the Baie des Chaleurs.

Control methods are generally practiced on lease areas and therefore are not successful at decreasing sea star densities in areas outside a lease. Sea stars will reinvade cleared areas and therefore continual efforts of removal are required. While the mop seems to offer the most efficient sea star control method for bottom culture, the significant initial investment required and its adaptation to open water conditions need to be considered. The dredge presents the unique advantage of being able to concomitantly remove sea stars during regular fishing activities and should be encouraged. Meanwhile, this method may target species of sea stars that are not of concern to shellfish culture. Some methods, such as the dredge, sea star traps and hand-picking do not destroy the sea stars and therefore allow for their use after collection. Although there are many potential uses for sea stars, none show any financial

advantage. In the case of off bottom culture and oyster bottom culture, the benefits of increased harvest yield clearly warrant the cost of control measures.

5.0 ACKNOWLEDGMENTS

The authors would like to thank Madeleine Nadeau, Denyse Hébert, François Bourque, Georges Cliché, Russell Mincher, Neil MacNair, Larry Barnett, Øivind Strand, Bob Thompson, Mamoru Kurata, David Hopp, Yvon Chiasson, Amédée Savoie, Clyde MacKenzie, Chris Somers, Gary Rogers, Bob Fortune, MarK Hanson, and Larry Barnett for their time and generosity in providing us with valuable information. We thank Bruno Frenette for his collaboration, Marie-Claude Paulin for revising papers and reports written in the French language and Gisèle Richard for helping us locate many articles. This literature review was supported by Pecten UPM/MFU Inc. and the Aquaculture Collaborative Research and Development Program (Department of Fisheries and Oceans).

6.0 LITERATURE CITED

Anonymous. 1994. Sea star traps look promising. Aust. Fish. 53 (1): 30-31.

Anonymous. 1995. Controlling Crown-of Thorn Starfish. The Great Barrier Reef marine park authority. http:www.reef.crc.org.au/publications/explore/feat45.html (accessed 7 February, 2006).

Anonymous. 2000. Sea star "Round Up" 2000. Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions http:www.marine.csiro.au/crimp/cleanup/cleanup.htm (accessed 11 September, 2005).

Anonymous. Dredging/beamtrawling/mopping. http:www.marine.csiro.au/crimp/nimpis/controlDetail.asp?ID=67 (accessed 20 February, 2006).

Barbeau, M. A. and H. Caswell. 1999. A matrix model for short-term dynamics of seeded populations of sea scallops. Ecol. Appl. 9 (1): 266-287.

Barbeau, M. A. and R. E. Scheibling. 1994. Behavioural mechanisms of prey size selection by sea star *Asterias vulgaris* Verrill and crabs *Cancer irroratus* Say preying on juvenile sea scallops *Placopecten magellanicus* Gmelin. J. Exp. Mar. Biol. Ecol. 180 (1): 103-136.

Barbeau, M. A., R. E. Scheibling and B. G. Hatcher. 1994. Effects of prey size and water temperature on predation of juvenile sea scallops *Placopecten magellanicus* by sea stars and crabs in laboratory and field experiments. Can. Tech. Rep. Fish. Aquat. Sci Rapp. Tech. Can. Sci. Halieut. (1): 1994.

Barbeau, M. A., R. E. Scheibling and B. G. Hatcher. 1998. Behavioural responses of predatory crabs and sea stars to varying density of juvenile sea scallops. Aquaculture 169: 87-98.

Barthelemy, G., N. DePauw and J. Joyce. 1991. Mechanical and biological control of the starfish *Asterias rubens* proliferation in the Bay of Quiberon (southern Brittany, France). Aquaculture and the environment. Spec. Publ. Eur. Aquacult. Soc. 14: 22p.

Boudreau, R., R. Fougere, L-A. Davidson and M. Niles. 2005. Fencing the seabed to protect sea scallops *Placopecten magellanicus* from predation. Can. Manuscr. Rep. Fish. Aquat. Sci. 2717: iv + 7p.

Bourque, F. and B. Myrand. 2003. Contrôler les prédateurs de moules dans les lagunes. Oui mais a quel prix. Activités 2001-2002. Direction de l'innovation et des technologies. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation: 51p.

Bourque, F. and B. Myrand. In Press. Traitement des collecteurs de moules à la saumure pour contrer la predation par les étoiles de mer. Bilan des travaux de 2000 à 2005. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation.

Bourque, F. and B. Myrand. 2002. Le traitement à la saumure des collecteurs de moules (*Mytilus edulis)* une solution incontournable pour réduire l'impact de la prédation des étoiles de mer. Activités 2000-2001. Direction de l'innovation et des technologies. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation. 90p.

Canadian Council of Ministers of the Environment, 2005. Guidelines for Compost Quality. PN 1340. 22p.

Comeau, M., M. Hanson, M. Mallet and F. Savoie. 2004. Stock status of the American lobster *Homarus americanus* in the Lobster Fishing Area 25. Fisheries and Oceans Canada Science and Canadian Science Advisory Secretariat Research Document 2004/054.

Dupont, S., K. Wilson, C. Dahlberg, and M. Thorndyke. 2006. The brittlestar *Amphiura foloformis* as a new model. Abstracts of the Annual Main Meeting of the Society for Experimental Biology, April 3-7, 2006, University of Kent at Canterbury, UK, A8.2

Flimlin, G. and B. F. Beal. 1993. Major predators of cultured shellfish. NRAC Bulletin No. 180.

Gaymer, C. F., J. H. Himmelman and L. E. Johnson. 2001. Distribution and feeding ecology of the sea stars *Leptasterias polaris* and *Asterias vulgaris* in the northern Gulf of St Lawrence Canada. J. Mar. Biol. Assoc. U. K. 81 (5): 827-843.

Gaymer, C. F., J. H. Himmelman and L. E. Johnson. 2002. Effect of intra and interspecific interactions on the feeding behaviour of two subtidal sea stars. Mar. Ecol. Prog. Ser. 232: 149-162.

Gaymer, C. F. C. Dutil and H. Himmelman. 2004. Prey selection and predatory impact of four major sea stars on a soft bottom subtidal community. J. Exp. Mar. Biol. Ecol. 313: 353-374.

Goggin, C. L. 1998. Proceedings of a meeting on the biology and management of the introduced sea star *Asterias amurensis* in Australian waters. Centre for research on introduced marine pests. Technical report no. 15. CSIRO Marine Research Hobart: 1-66.

Gudbjarnason, S. 1999. Bioactive marine natural products. Rid Fiskideildar/J. Mar. Res. Inst.16:107-110.

Hébert, D., M. Nadeau, N. Presse and S. Vigneau. 2006. Contrôle des prédateurs avec les dragues à pétoncles et le Faubert. In: Nadeau, M. and G. Tita (eds.). Atelier de travail " prédation du pétoncle et gestion des ensemencements", Îles-de-la-Madeleine, 29 février – 1er mars 2004. Direction de l'innovation et des technologies, MAPAQ. Compte rendu no° 24. 54p.

Heffernan, M. L. 1999. A review of the ecological implications of mariculture and intertidal harvesting in Ireland. Irish Wildlife Manuals 7.

Hendrix, M. L. 2006. Dutch know-how comes to Maine, new mussel barge launched in Bar Harbor. Northern Aquaculture, May/June 2006: 14-15.

Heuser G. F. and J. McGinnis. 1946. Sea star Meal in Chick Rations. Bull of Bingham Ocean. Coll. 9 (3) (10-12).

Himmelman, J. H., and C. Dutil. 1991. Distribution population size-structure and feeding of subtidal sea stars in the northern Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 76: 61-72.

Hokkaido Environment Bio-Sector, Ltd. 2004. Disposal processing of starfish. Available from http://www.kankyo-v.co.jp/english/starfish.html [accessed July 5, 2006].

Inglis, G. J. and N. Gust. 2003. Potential indirect effects of shellfish culture on the reproductive success of benthic predators. J. Appl. Ecol. 40: 1077-1089.

Ito, H. 1991. Successful HOTAC method for developing scallop sowing culture in the Nemuro district of east Hokkaido northern Japan. *In* Marine Ranching Proceedings of the Seventeenth US-Japan Meeting on Aquaculture. Ise Mie Prefecture Japan October 16-18 1988. R. S. Svrjcek. NOAA Technical Report NMFS 102: 107-116.

Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions. 1999. National Control Plan.: for the introduced marine pest northern Pacific sea star (*Asterias amurensis*). Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions Final report. http:www.deh.gov.au/coasts/imps/workshop-sea star.html.

Lee, C. F. 1948. Technological studies of the starfish Part 1. Commercial Fisheries Review. 10 (1): 1-6.

Lee, C. F. 1951. Technological Studies of the Sea star. Part II – Chemical Composition. Fishery Leaflet 391, (Washington DC) p. 7-14.

MacKinnon, C. M., R. Gallant and B. Gillis. 1993. Some observations on starfish predation on mussel spat collectors. P. E. I. Department of Agriculture Fisheries and Forestry. Tech Rep. Ser. 208: 28p.

Martin, R. and C. Proctor. 2000. Tasmanian Marine Farm Marine Pest Monitoring Project. Centre for research on Introduced Marine Pests. www. marine. csiro. au crimp Report MFMP Final Rpt. pdf.

Martindale Feed Mill. Quality Feed. Affordable Prices. [online]. Available from http://www.martindalefeed.com/ (accessed February 16, 2006).

McEnnuly, F. R., N. J. Bax, B. Schaffelke and M. L. Campbell. 2001. A review of rapid response options for the control of abwmac listed introduced marine pest species and related taxa in australian waters. Centre for research on introduced marine pests. Technical report no. 23. Csiro Marine Research Hobart. 101 pp.

Mead, A. D. 1901. The natural history of the star-fish. Contributions from the Biological Laboratory of the U. S. Fish Commission Woods Hole Massachusetts Vol X1X: 203-224.

Menge, B. A. 1986. A preliminary study of the reproductive ecology of the sea stars *Asterias vulgaris* and *A. forbesi* in New England. Bulletin of Marine Science 39 (2): 467-476.

Morse, R. E., F.P. Griffiths and R.T. Parkhurst. 1946. Preliminary Report on Eight Weeks of Comparative Feeding of Protein Equivalent Diets containing Fish Meal, Crab Meal and Sea star Meal to Rhode Island Red Chicks, Bull of Bingham Ocean. Coll. 9 (3) (13-16).

Nadeau, M. and G. Cliche. 1998. Predation of juvenile sea scallops *Placopecten magellanicus* by crabs *Cancer irroratus* and *Hyas* sp. and starfish *Asterias vulgaris, Leptasterias polaris* and *Crossaster papposus* J. Shellfish Res. 17 (4): 905-910.

Nadeau, M. and D. Hébert. 2005. Impact du contrôle des prédateurs sur la survie des pétoncles géants ensemencés. In: Cliche, G. and F. Coulombe (eds.). 4e réunion anuelle de transfert de technologie. REPERE II. MAPAQ, No. 22: 87-89.

Nadeau, M., D. Hébert, J. Arseneau, F. Aucoin, L. Bourdages, Y. Chevarie, J. G. Turbide, C. Vigneau and S. Vigneau. 2004. Impact de contrôle des prédateurs sur le survie des pétoncles géants *Placopecten magellanicus* ensemencés. Direction de l'innovation et des technologies. Bilan des réalisations 2002-2004: 44-45.

Nadeau, M. and G. Cliche. 2002. Travaux sur la prédation réalisés en 1998 et 1999. In: Nadeau, M. and P. Carrier (eds.). 1ère réunion annuelle de transfert de technologie, REPERE II, MAPAQ. No.9:82p.

Needler, A. W. H. 1939a. How to avoid damage caused by starfish. Fish. Res. Board Can. Circular no. 7: 2p.

Needler, A. W. H. 1939b. Starfish the oyster's worst enemy in our waters. Fish. Res. Board Can. Circular no. 6: 2p.

Nelson, J. R., 1946. Observations on the Occurrence and Possible uses of Sea star. Bull of Bingham Ocean. Coll. 9 (3) (31-32).

O'Neill, S. M., A. M. Sutterlin and D. Aggett. 1983. The effects of size-selective feeding by starfish *Asterias vulgaris* on the production on mussels *Mytilus edulis* cultured on nets. Aquaculture 35: 211-220.

Pecten UPM/MFU. 2002. Rapport d'activités de Pecten UPM/MFU concernant le programme d'ensemencement des pétoncles. 26p.

Presse, N., S. Vigneau, D. Hébert and M. Nadeau. 2005. Essai de réduction des densités d'étoiles de mer par la technique du Faubert sur les sites d'ensemencement du pétoncle géant *Placopecten magellanicus* aux Îles-de-la-Madeleine. In: G. Cliché and F. Coulombe (eds.), 4e réunion annuelle de transfert technologique REPERE II, no.22: 136p.

Presse, N., S. Vigneau, D. Hébert and M. Nadeau. 2003. Essai de réduction des densités d étoiles de mer par la technique du faubert sur les sites d'ensemencement du pétoncle géant *Placopecten magellanicus* aux Îles-de-la-madeleine. Ministère de l'Agriculture des Pêcheries et de l'Alimentation. 28p.

Pryor, M. G., J. Parsons and C. Couturier. 1999. Temporal distribution of larval and post-set blue mussel *Mytilus edulis* and *M. trossulus* and starfish *Asterias vulgaris* at mussel culture sites in Newfoundland. Contributed Papers Aquaculture Canada '99 Victoria BC 26-29 October '99. no. 99-4 pp. 40-42. Bull. Aquacult. Assoc. Can.

Ringrose, R. C. 1946. Sea star Meal Feeding Experiment with Chicks. Bull of Bingham Ocean. Coll. 9 (3) (17-19).

Shearer, L. W. and C. L. MacKenzie Jr. 1961. The effects of salt solutions of different strengths on oyster enemies. Proceedings of the national shellfisheries association 50: 97-103.

Shell Horizons Inc. 1998. US Largest Wholesaler of Seashells and Seashell Products, Finest Quality Seashells and Souvenirs Since – 1976. [online]. Available from http://www.shellhorizons.com/ (accessed July 5, 2006)

Sloan, N.A. 1984. Echinoderm fisheries of the world: A review. Proceedings of the Fifth International Echinoderm Conference: 109-123.

Smith, G.F.M. 1940. The removal of starfish from oyster beds by mops. Fish. Res. Board Can. Prog. Rep. 28: 5-6.

Strand, Ø. E., S. Grefsrud, T. Strohmeier, E. Helland, T. Helland and G. Hamre. 2003. Fenced farming a prerequisite for scallop *Pecten maximus* seabed culture in Norway. 14th International Pectinid Workshop St. Petersburg Florida U. S. A. p. 27.

U.S. Fish and Wildlife service. 1946. Natural history and methods of controlling the starfish, *Asterias forbesi* Desor Division of Fishery Biology. United States Department of the Interior Fish and Wildlife Service 169: 7p.

Ventilla, R. F. 1982. The scallop industry in Japan. Adv. Mar. Biol. 20: 309-382.

Whitson D. and H.W. Titus. 1946. The use of sea star meal in chick diets. Bull of Bingham Ocean. Coll. 9 (3) :24-27.

Witman, J. D., S. J. Genovese, J. F. Bruno, J. W. McLaughlin and B. I. Pavlin. 2003. Massive prey recruitment and the control of rocky subtidal communities on larger spatial scales. Ecol. Monogr. 73 (3): 441-462.

Xu, J., T. Zhang, Z. Guo, S. Ji, Z. Leng, S. Zhou, X. Jiang, Y. Liu, and B. Lu. 1995. Studies on Comprehensive Utilization of Sea Star. Shandong fisheries/Qilu Yuye. Yantai. Vol. 12, no. 1 : 38-41.

Table 1. Average and range of sea star densities found on the three Pecten sites during the 2005 video evaluations.

Site	**Average Density (/m^2)**	**Range of Density (/m^2)**
Baie des Chaleurs	0.72	0.19 - 2.50
Miramichi	0.06	0.01 - 0.09
Détroit	0.12	0.09 - 0.15

Table 2. Summary of control methods with description, where it is used, cost and corresponding papers.

Control Method	Brief Description	Where used	Estimated Costs	Corresponding papers
Sea star mop (Faubert)	In general, a sea star mop is made up of a number of cotton bundles (ranging from 7 to 19) attached to a frame (such as an 8 to10 foot iron bar), which is pulled behind a boat (see figure 3) (US fish 1946). As the sea star mop passes over the sea bottom, sea stars become entangled in the threads of the cotton bundles. Once on deck, the starfish are either removed by hand, to be disposed of later, or killed by submerging the mop into a basin containing hot water. The mop is best used on areas of a medium scale with high densities of sea stars.	Canada, US, Japan, France	Presse *et al.* (2005) stated an estimated cost of $43,232.60 ($0.06/sea star) to cover a 4 km^2 area with the Faubert over 16 days (roughly $2702.03 per day). This includes the cost of the initial set up of two boiler systems and two fauberts as well as the replacement of cotton bundles and cost required to run the boat. The operational cost of a US oyster company commercially using the mop was estimated at $1400 per day. ~ $20,000 initial cost to equip boat with two boiler systems	Anon.(http:www.marine.csiro.au/crimp/nimpis/controlDetail.asp?ID=67) Barthelemy *et al.*, 1991 Bourque and Myrand, 2003 Goggin, 1998. Heffernan, 1999. Ito, 1991. Lee, 1948. McEnnuly *et al.*, 2001 Needler, 1939a. Pecten UPM/MFU, 2002. Presse *et al.*, 2003 Presse *et al.*, 2005 Smith, 1940. U.S. Fish and Wildlife service, 1946.

Dredge	The dredge is non selective, therefore, sea stars are collected as well as oysters and scallops as the dredge passes over the sea bottom. Sea stars then need to be picked out by hand to be disposed of later. There are dredges with slight modifications such as the "roller dredge", which uses a front roller to suspend the sea stars before collecting them in a rear bag, and the specialized dredge used in France to selectively collect *Asterias rubens*. The dredge is best used for medium to small scale areas with high densities of sea stars.	Canada, US, Japan, France, New Zealand	$47, 093 ($0.052 per sea star) to cover a total of 17.9 km^2, which includes paying for the collection of sea stars ($0.10 to $0.25 per pound to fishermen), the compost program ($0.036/kg) and wages (Presse *et al.*, 2005; D. Hébert, pers. comm., 2006)	Barthelemy *et al.*, 1991. Goggin, 1998. Hébert *et al.* 2006. McEnnuly *et al.*, 2001. Nadeau and Hébert, 2005. Presse *et al.*, 2005.
Sea star traps	Catch rates of sea star traps are highly variable. Some types of sea star traps include Whayman-Holdsworth sea star traps, Tasmanian designed sea star traps, and Japanese designed sea star traps. Best use for small enclosed areas were there is a high abundance of sea stars and low alternate food sources available.	Canada, Japan, Australia	~$65.00 per cage Cost to run boat and wages. Cost to replace lost or broken cages	Anon., 1994. Goggin, 1998. Martin, and Proctor, 2000. McEnnuly *et al.*, 2001. Needler, 1939b.
Fences	Fences are an exclusion method. Most research to date concerning the use of fences has focused on the exclusion of crabs.	Norway, Canada	The cost of using a fencing method would include the cost of the fence ($8.45/m) and labour wages for initial set-up, which may include divers, as well as regular	Anon., 1995. (http:www.reef.crc.org.au/publications/explore/feat45.html Boudreau *et al.*, 2005.

			maintenance.	Strand *et al.*, 2003.
Brine	Mussel spat collectors are dipped in salt brine for 30 seconds to kill sea stars. The best time to this is in mid-august before the sea stars reach 15 mm in size. Takes approximately 5 days to do 60 mussel lines.	Canada	Includes cost to run boat, wages and brine solution.	Bourque and Myrand 2002. MacKinnon *et al.*, 1993. Shearer and MacKenzie Jr., 1961.
Lime	Mussel spat collectors are dipped in a 40g/l solution of hydrated lime before sea stars reach 15 mm in size.	Canada	Includes cost to run boat, wages and lime. The estimated costs vary from $20 to $100 per line of collectors.	MacKinnon *et al.*, 1993.
Diving/ hand picking	Sea stars can be collected by hand off of mussel collectors, mussel socks or scallop and oyster growing structures. Approximately one hour out of an eight hour day is dedicated to the removal of sea stars during the sorting of seed. Sea stars are also collected by hand off the sea bottom in shallow waters. During the harvesting of oysters, approximately 10% of the time is dedicated to sea star removal.	Australia, Canada	Cost of wages	Anon., 2000. Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions, 1999. Ventilla, 1982.

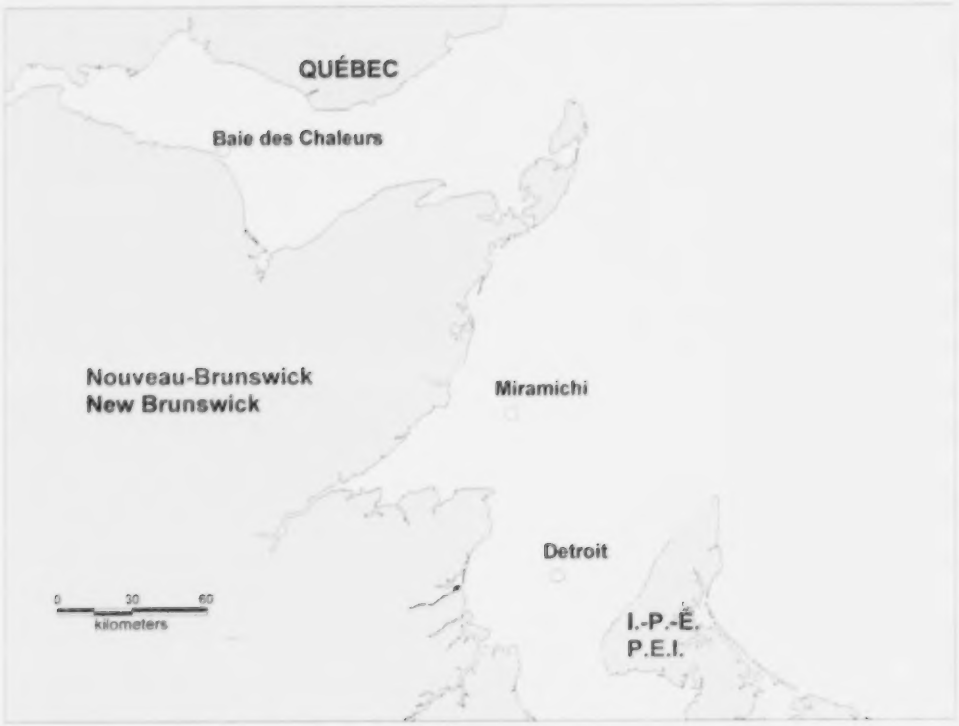

Figure 1. Map showing scallop enhancement sites of Pecten UPM –MFU Inc.

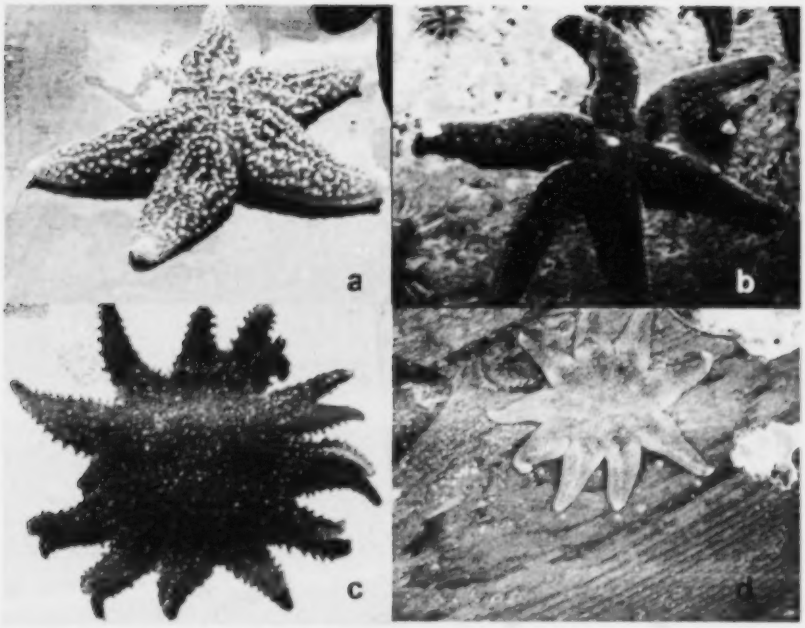

Figure 2. Species of sea stars found in the Southern Gulf of St. Lawrence: a) *Asterias vulgaris*; b) *Leptasterias polaris*; c) *Crossaster papposus*; d) *Solaster endeca*.

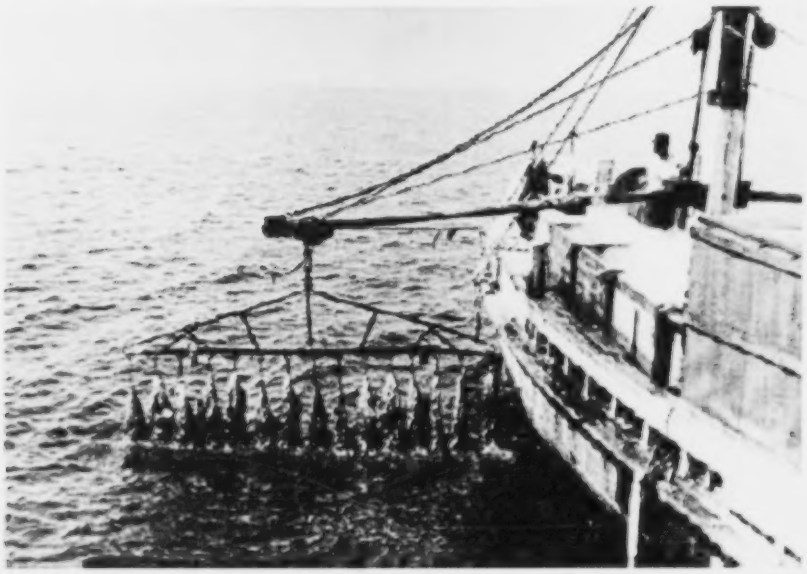

Figure 3. Sea star mop.

(Source: http://www.nefsc.noaa.gov/press_release/2000/starfishmop1.jpg)

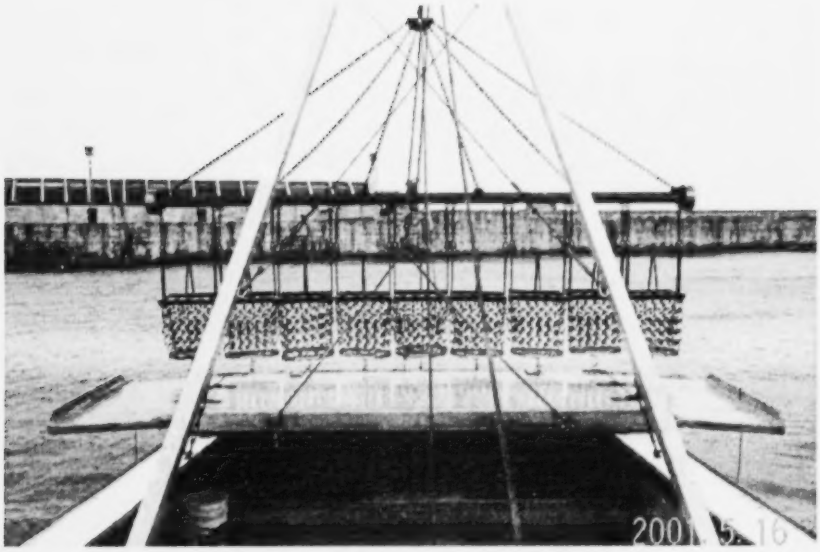

Figure 4. Scallop dredge used in Cape Tormentine, New Brunswick.

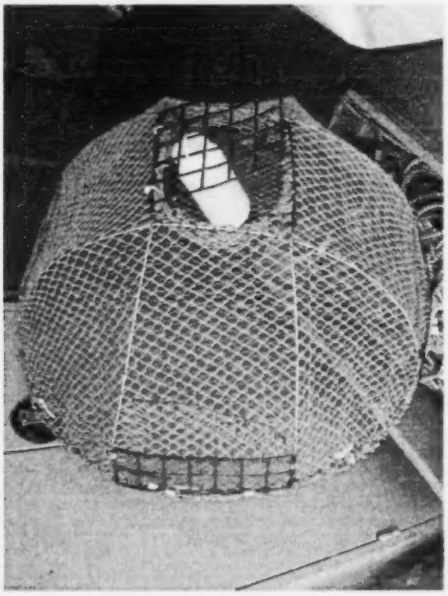

Figure 5. Sea star trap used on the Magdalen Islands.

(Source: picture courtesy of François Bourque and Jacques Richard)

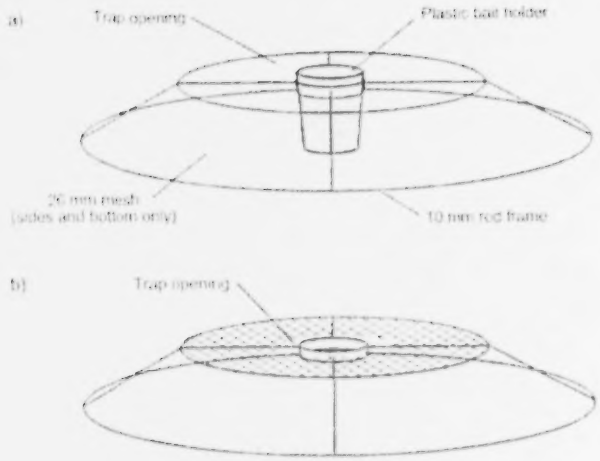

Figure 6. Whayman-Holdsworth Sea star traps.

(Source: Martin and Proctor, 2000)

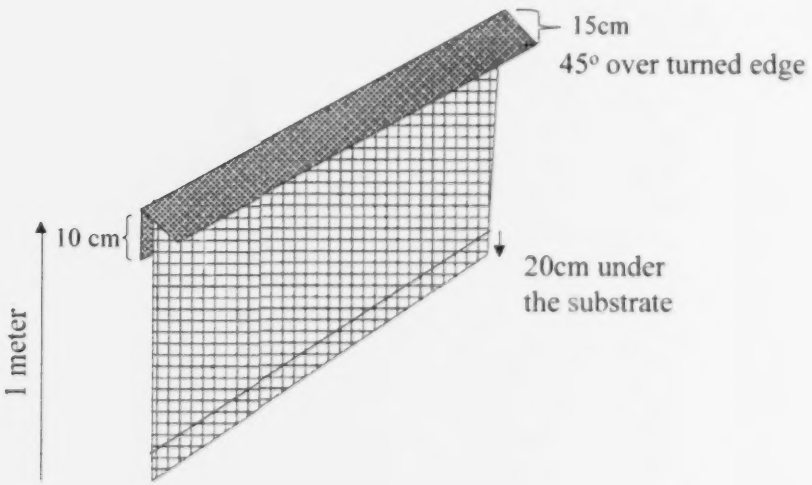

Figure 7. Fence with 45° overturned edge.

(Source: Boudreau et al., 2005)

7.0 ANNEX 1

Annex 1. List of literature pertaining to sea star control methods not cited in the text.

Anonymous. 1990. Solving the mystery of good and poor harvests and Developing a system of techniques suited to the mode of life of shellfish. Yamaha Fishery Journal 34.

Anonymous. 2004. Ecology of the northern sea star. http:www.clarku.edu/departments/biology/biol201/2004/jcurtis (accessed 6 March, 2006).

Avault, J. W. Jr. 1998. Predators and pests of mollusks Oysters clams and mussels. Aquacult. Mag. 24 (1): 56-61.

Barbeau, M. A. and R. E. Scheibling. 1994. Procedural effects of prey tethering experiments Predation of juvenile scallops by crabs and sea stars. Mar. Ecol. Prog. Ser. 111 (3): 305-310.

Barbeau, M. A. and R. E. Scheibling. 1994b. Temperature effects on predation of juvenile sea scallops *Placopecten magellanicus* Gmelin by sea stars *Asterias vulgaris* Verrill and crabs *Cancer irroratus* Say J. Exp. Mar. Biol. Ecol. 182 (1): 27-47.

Barbeau, M. A., B. G. Hatcher, R. E. Scheibling, and A. W. Hennigar, L. H. Taylor and A. C. Risk. 1996. Dynamics of juvenile sea scallop *Placopecten magellanicus* Gmelin and their predators in bottom seeding trials in Lunenburg Bay Nova Scotia. Can. J. Fish. Aquat. Sci. 53: 2494-2512.

Barbeau, M. A., R. E. Scheibling, B. G. Hatcher, L. H. Taylor, A. W. Hennigar. 1994b. Survival analysis of tethered juvenile sea scallops *Placopecten magellanicus* in field experiments Effects of predators scallop size density site and season. Mar. Ecol. Prog. Ser. 115 (3): 243-256.

Barthelemy, G. 1992. Lutte biologique contre la prolifération de l'étoile de mer *Asterias rubens* en baie de Quiberon. Société française de Malacologie. Les mollusques marins Biologie et aquaculture, 14: 93-106.

Beattie, J. H., B. Blake and D. Herren. 1995. Improving survival of planted juveniles of the geoduck clam *Panopea abrupta* using predator exclusion devices. J. Shellfish Res. 14 (1): 260.

Bergh, O. and Ø. Strand. 2001. Great scallop *Pecten maximus* research and culture strategies in Norway a review. Aquaculture International 9: 305-318.

Bourque, F. and B. Myrand. 2005. Impact du calage des lignes pour le contrôle de la fixation secondaire de moule. Direction de l'innovation et de la technologie 1. 50: 37p.

Brulotte, S. and M. Giguère. 2005. Bilan des travaux sur les espèces associées au captage de pétoncle aux Île de la Madeleine {In}: Cliche, G. and F. Coulombe (eds.). 4^{e} réunion annuelle de transfert de technologie REPERE II MAPAQ No.22: 17-29.

Burnett, A. L. 1960. The mechanism employed by the starfish *Asterias forbesi* to gain access to the interior of the bivalve. Ecology 41: 583-584.

Burton, R. W. 1966. Starfish Friend or Foe State of Rhode Island Department of Natural Resources Division of Conservation. Leaflet no. 21.

Cliche. G., C. Cyr and D. Hébert. 2005. De faible densité d'étoile de mer et de moules dans les paniers de préélevage nuisent-t-elles à la croissance et la survie des pétoncles *Placopecten magellanicus*. {In}: Cliche, G. and F. Coulombe (eds). 4^{e} réunion annuelle de transfert de technologie REPERE II MAPAQ No.22: 43-50.

Cliche, G., M. Giguère and S. Vigneau. Dispersal and mortality of sea scallop *Placopecten magellanicus* Gmelin juveniles seeded on the sea bottom off the Îles-de-la-Madeleine. J. Shellfish Res. 13: 565-570.

Cliche, G., S. Vigneau and G. Vigneau. 1997. Compte rendu de la participation a la mission sur l'élevage du pétoncle réalisée au Japon entre le 2 Août et le 9 Août 1997. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, Direction de l'innovation et des technologies and Association des Pêcheurs de pétoncles des Îles-de-la-Madeleine iii + 11p.

d'Entremont, J. and M. A. Barbeau. Impact of multiple predators: sea star and crab predation on juvenile scallops. Department of Biology University of New Brunswick Bag Service #45111 Fredericton, New Brunswick Canada E3B 6E1. Masters thesis, UNB.

Dolmer, P. 1998. The interactions between bed structure of *Mytilus edulis* L. and the predator *Asterias rubens* L. J. Exp. Mar. Biol. Ecol. 228: 137-150.

Dommisse, M. and D. Hough. 2004. Controlling the northern Pacific Sea star *Asterias amurensis* in Australia. Final Report for the Australian government department of the environment and heritage. 52p.

Drolet, D., J. H. Himmelman and R. Rochette. 2004. Use of refuges by the ophiuriod *Opiopholis aculeata* Contrasting effects of substratum complexity on predation risk from two predators. Mar. Ecol. Prog. Ser. 284: 173-183.

Fleury, P.-G., C. Mingant and A. Castillo. 1996. A preliminary study of the behaviour and vitality of reseeded juvenile great scallops of three sizes in three seasons. Aquacult. Int. 4 (4): 325-337.

Franz, D. R., E. K. Worley and A. S. Merrill. 1981. Distribution patterns of common sea stars of the Middle Atlantic Continental Shelf of the Northwest Atlantic Gulf of Maine to Cape Hatteras. Biol. Bull. 160 (3): 394-418.

Galtsoff, P. S. and V. L. Loosanoff. 1939. Natural history and method of controlling the starfish *Asterias forbesi* Desor. Bulletin of the US Bureau of Fisheries 49: 75-132.

Gangney, A., P. Rivalan, P. M. A. Barbeau and M. Nadeau. 2005. Modélisation de la dynamique des populations de pétoncles géants *Placopecten magellanicus* ensemencés aux Îles-de-la-Madeleine Québec Canada. Rapport final project UNB SODIM MITACS 1 er juin 2003 30 novembre 2005.

Garza, C. 2005. Prey productivity effects on the impact of predators of the mussel *Mytilus califonianus* Conrad. J. Exp. Mar. Biol. Ecol. 324: 76-88.

Gaudet, M. and Y. Bastien. Rapport de mission sur la pectiniculture au Japon. Ministère de l'Agriculture des Pêcheries et de l'Alimentation sous-ministeriat aux pêches maritimes. Direction de la recherche scientifique et technique. Station de recherche aquicole des Îles-de-la-Madeleine 190 rue principale C. P. 658 Cap-aux-Meules G0B IBO.

Gaymer, C. F. and J. H. Himmelman. 2002. Mussel beds in deeper water provide an unusual situation for competitive interactions between the sea stars *Leptasterias polaris* and *Asterias vulgaris*. J. Exp. Mar. Biol. Ecol. 277 (1): 13-24.

Gaymer, C. F. C. Dutil and H. Himmelman. 2004. Prey selection and predatory impact of four major sea stars on a soft bottom subtidal community. J. Exp. Mar. Biol. Ecol. 313: 353-374.

Gaymer, C. F., J. H. Himmelman and L. E. Johnson. 2001b. Use of prey resources by sea stars *Leptasterias polaris* and *Asterias vulgairs* a comparison between field observations and laboratory experiments. J. Exp. Mar. Biol. Ecol. 262: 13-30.

Gudbjarnason, S. Bioactive marine natural products. Rid Fiskideildar J. Mar. Res. Inst. 16: 107-110.

Gunthorpe, L., J. Mercer, C. Rees and T. Theodoropoulous. 2001. Best practices for the sterilisation of aquaculture farming equipment :A case study for mussel ropes. Marine and Freshwater Resources Institute report 41: vi + 48p.

Hatcher, B. G., R. E. Scheibling, M. A. Barbeau, A. W. Hennigar, L. H. Taylor and A. J. Windust. 1996. Dispersion and mortality of a population of sea scallop *Placopecten magellanicus* seeded in a tidal channel. Can. J. Fish. Aquat. Sci. 53: 38-54.

Hulbert, A. W. The ecological role of Asterias vulgaris in three subtidal communities. In Echinoderms present and past.

Johnson, D. B., P. J. Moran and S. Driml. 1990. Evaluation of a crown-of-thorns starfish *Acanthaster planci* control program at Grub Reef central Great Barrier Reef Coral Reefs 9: 167-171.

Kaiser, M. J. 1996. Starfish damage as an indicator of trawling intensity. Mar. Ecol. Prog. Ser. 134: 303-307.

Keough, M. J. and A. J. Butler. 1979. The role of Asteroid predators in the organization of a sessile community on pier pilings. Mar. Biol. 51: 167-177.

Lawrence, J. M., M. Byrne, L. Harris, B. Keegan, S. Freeman and B. C. Cowell. 1999. Sublethal arm loss in *Asterias amurensis A. rubens A. vulgaris* and *A. forbesi* Enchinodermata Asteroidea. Vie Milieu 49 (1): 69-73.

Loosanoff, V. L. 1961. Biology and methods of controlling the starfish *Asterias forbesi* Desor. Fisheries Leaflet US Fish and Wildlife Service 520: 1-11.

Loosanoff, V. L. and J. B. Engle. 1942. Use of lime in controlling the starfish. US Fish and Wildlife Service Research Report 2: 1-29.

Loosanoff, V. L. Effects of sea water of reduced salinities upon starfish *A. forbesi* of Long Island Sound. Trans. Conn. Acad. XXXV1: 813-833.

MacKenzie Jr, C. L. 1977. Use of quicklime to increase oyster seed production. Aquaculture 10: 45-51.

MacKenzie Jr, C. L. and R. Pikanowski. 1999. A decline in starfish *Asterias forbesi* abundance and a concurrent increase in northern Quahog *Mercenaria mercenaria* abundance and landings in the Northeastern United States. Marine Fisheries Review 6 (2): 66-71.

McEdward, L. R. and B. G. Miner. 2001. Larval and life-cycle patterns in echinoderms. Can. J. Zool. 79: 1125-1170.

Menge, B. A. 1979. Coexistence between the sea stars *Asterias vulgaris* and *A. forbesi* in a heterogeneous environment a non-equilibrium explanation. Oecologia 41 (3): 245-272.

Meyer, T. L., R. A. Cooper and K. J. Pecci. 1981. The performance and environmental effects of a hydraulic clam dredge. Marine Fisheries Review 43 (9): 14-22.

Miron, G., T. Landry and N. MacNair. 2002. Predation potential by various epibenthic organisms on commercial bivalve species in Prince Edward Island preliminary results. Can. Tech. Rep. Fish. Aquat. Sci. 2392.

Morissette, S. and H. Himmelman. 2000. Subtidal food thieves interactions of four invertebrate kleptoparasites with the sea star *Leptasterias polaris*. Anim. Behav. 60 (4): 531-543.

Morissette, S. and J. H. Himmelman. 2000. Decision of the asteroid *Leptasterias polaris* to abandon its prey when confronted with its predator the asteroid *Asterias vulgaris*. J. Exp. Mar. Biol. Ecol. 252 (2) 151-157.

Nadeau, M. and G. Cliche. 2001. Optimisation du préélevage sur les capteurs. Contrôle des étoiles de mer. 2^{e}réunion annuelle de transfert de technologie REPERE II 10 : 29p.

Nadeau, M. 2001. Est-il possible de contrôler la fixation des étoiles de mer *Asterias vulgaris* sur les capteurs de pétoncles *Placopecten magellanicus*. {In}: MAPAQ, Direction de l'innovation et des technologies. Activités 2000-2001: 37-38.

Nadeau, M. 2002. La difficulté de contrôler la fixation des étoiles de mer *Asterias vulgaris* sur les capteurs de pétoncle. {In}: MAPAQ, Direction de l'innovation et des technologies. Activités 2001-2002: p :41.

Nadeau, M. 2002. Les étoiles de mer *Asterias vulgaris* retrouvées dans les capteurs peuvent-elles compromettre la survie de pétoncle. {In}: MAPAQ, Direction de l'innovation et des technologies. Activités 2001-2002: p :40.

Needler, A. W. H. 1940. Use of quicklime for killing starfish on oyster grounds. Fish. Res. Board Can. Prog. Rep. 1: 2p.

O'Neill, S. M. 1981. Size selective feeding behaviour and feeding rates of the starfish *Asterias vulgaris* on cultured mussels *Mytilus edulis*. B.Sc. Thesis Memorial University, St. John's, NFLD. 54p.

Peterson, C. H. 1979. The importance of predation and competition in organizing the intertidal epifaunal communities of Barnegat Inlet New Jersey. Oecologia 39: 1-24.

Powell, E. N., J. M. Klinck, E. E. Hofmann and S. Ford. 1997. Varying the timing of oyster transplant Implications for management from simulation studies. Fish. Oceanogr. 6 (4): 213-237.

Pryor, M. and G. J. Parsons. 1999. Larval distribution of blue mussel *Mytilus edulis* and *M. trossulus* and predatory starfish *Asterias vulgaris* during a 12-hour tidal cycle. Contribution Papers Aquaculture Canada '99 Victoria BC 26-29 October 1999. no. 99-4. Bull. Aquacult. Assoc. Can.

Riemann, B. and E. Hoffmann. 1991. Ecological consequences of dredging and trawling in the Limfjord Denmark. Mar. Ecol. Prog. Ser. 69: 171-178.

Roussy, M., G. Cliche G. and M. Giguère. 1994. Caractérisation et éradication des prédateurs du pétoncle géant *Placopecten magellanicus* aux Îles-de-la-Madeleine en 1993. Direction Générale des Pêches et de l'Aquaculture Commerciales. Direction de la recherche scientifique et technique 15: 85p.

Saier, B. 2001. Direct and indirect effects of sea stars *Asterias rubens* on mussel beds *Mytilus edulis* in the Wadden Sea. Journal of Sea Research 46: 29-42.

Sloan, N. A. 1985. Echinoderm fisheries of the world: A review. *{In}:* Echinodermata proceedings of the Fifth International Echinoderm Conference, Galway, 24-29 September 1984. B. F. Keegan and B. D. S. O'Connor (eds):109-124.

Smith, G. F. M. 1940. The removal of starfish from oyster beds by mops. Fish. Res. Board Can. Prog. Rep. 28: 5-6.

Sommer, U., B. Meusel and C. Stielau. 1999. An experimental analysis of the importance of body-size in the sea star-mussel predator-prey relationship. Acta Oecologica 20 (2): 81-86.

Spencer, B. E. 1991. Predators and methods of control in molluscan shellfish cultivation in north European waters. Spec. Publ. Eur. Aquacult. Soc. 16: 309-337.

Spencer, B. E. 1991. Predators and methods of control in shellfish cultivation. Aquaculture and the Environment. Spec. Publ. Eur. Aquacult. Soc. 14: 303p.

Strand, Ø., E. S. Grefsrud, G. A. Haugum, G. Bakke, E. Helland and T. E. Helland. 2004. Release strategies in Scallop *Pecten maximus* sea ranching vulnerable to crab predation. *{In}:* Stock enhancement and sea ranching developments pitfalls and opportunities (K. M. Leber S. Kitada H. L. Blankenship and T. Svasand, eds). Blackwell Publishing Ltd. UK. pp. 544-555.

Suyehiro, Y., H. Kabasawa and I. Anayama. 1975. On extermination of starfishes. {*In*} :Collected Abstracts and Papers of the International Conference on Marine Parks and Reserves. Tokyo Japan 12-14 May 1975 (T. Tamura M. Uda Y. Hiyama M. Horikoshi T. Okutani K. Deguchi and H. Uchida, eds). Bulletin of the Marine Park Research Stations 1 (2): pp 28-29.

Thieltges, D. W. 2005. Benefit from an invader American slipper limpet *Crepidula fornicata* reduces star fish predation on basibiont European mussels. Hydrobiologia 541: 241-244.

Thrush, S. F. 1988. Behavioural observations on sublittoral populations of starfish in Lough Hyne. Ir. Nat. J. 22 (10): 430-436.

Wilson, U. A. W. and A. R. Brand. 1994. Nowhere to hide: Predator impact on seeded scallops. Can. Tech. Rep. Fish. Aquat. Sci 118.

Wong, M. C. and M. A. Barbeau. 2003. Effects of substrate on interactions between juvenile sea scallops *Placopecten magellanicus* Gmelin and predatory sea stars *Asterias vulgaris* Verrill and rock crab *Cancer irroratus* Say. J. Exp. Mar. Biol. Ecol. 287: 155-178.

Wong, M. C. and M. A. Barbeau. 2005. Prey selection and the functional response of sea stars *Asterias vulgaris* Verrill and rock crabs *Cancer irroratus* Say preying on juvenile sea scallops *Placopecten magellanicus* Gmelin and blue mussels *Mytilus edulis* Linnaeus. J. Exp. Mar. Biol. Ecol. 327: 1-21.

Wong, M. C., L. A. Davidson, L. A. Grecian and M. A. Barbeau. Predation on juvenile scallops *Placopecten magellanicus* in the Northumberland Strait. Department of Biology University of New Brunswick Fredericton NB and Department of Fisheries and Oceans, Moncton NB.

Wong, M. C., M. A. Barbeau, A. W. Hennigar and S. M. C. Robinson. 2005. Protective refuges for seeded juvenile scallops *Placopecten magellanicus* from sea star *Asterias* spp. and crab *Cancer irroratus* and *Carcinus maenas* predation. Can. J. Fish. Aquat. Sci. 62: 1766-1781.